NRL Report 7418

Termite Resistance of Polymeric Materials Phase 2-Nontoxic Polymers

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July 6, 1972

NAVAL RESEARCH LABORATORY
Washington, D.C.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

TERMITE RESISTANCE OF POLYMERIC MATERIALS, PHASE 2—NONTOXIC POLYMERS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

This is a final report on this phase of the problem; work is continuing on other phases

5. AUTHOR(S) (First name, middle initial, last name)

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6. REPORT DATE July 6, 1972	7a. TOTAL NO. OF PAGES 24	7b. NO. OF REFS 10
8a. CONTRACT OR GRANT NO. NRL Problem G04-01 b. PROJECT NO. RR 104-03-41-5503 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 7418 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Naval Facilities Engineering Command) Washington, D.C. 20360

13. ABSTRACT

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Extreme differences in activity of the different test beds were found. The two tropical beds were about equal and by far the most active and consistent. The results emphasize the need for such very active sites for natural exposure testing. Laboratory jar colonies proved to be an effective means of accelerated evaluation of nontoxic materials.

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(Continued)

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Termite resistance						
Subterranean termites						
Natural exposures						
Tropical environments						
Captive colonies						
Polymeric materials						
Plastics						
Polyvinyl chloride						
Elastomers						
Nontoxic modifications						
Inorganic fillers						
Plastic hardness						
Thickness						
Surface Smoothness						
Toxic additives						
Insecticide						
Creosote						

resistance to the various termite species. There was a very definite relation between hardness and termite resistance. Increasing hardness from 10 to 30 (Shore D durometer scale) reduced the number of PVC failures by 86%.

The highest overall performance for flexible materials was obtained with non-PVC formulations. Of these the two best were ethylene propylene rubber and chlorosulfonated polyethylene. These materials were about equal to the best toxic formulations from Phase 1, but they offer the additional advantages of being innocuous to man and the environment and the promise of very long service life without loss of effectiveness.

CONTENTS

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PROBLEM STATUS

This is a final report.

AUTHORIZATION

NRL Problem G04-01
Project RR 104-03-41-5503

Manuscript submitted March 29, 1972.

TERMITE RESISTANCE OF POLYMERIC MATERIALS
PHASE 2 – NONTOXIC POLYMERS

INTRODUCTION

Damage to materials and equipment by subterranean termites has long been a serious problem. In tropical areas damage is more rapid and severe because of the constant activity of more aggressive tropical termite species, principally of the two genera *Coptotermes* and *Heterotermes*. The problem has been greatly intensified in recent years by the introduction of many new plastics of unknown termite resistance and by extensive use of these materials in military operations in the tropics. Furthermore, the situation has been aggravated by the recent discovery of infestations of the Formosan subterranean termite *Coptotermes formosanus* Shiraki (1) in southern U.S. coastal areas.

It is generally recognized that most woods used in construction are susceptible to termite attack, and adequate protective treatments and barriers are usually employed. The necessity and possibilities for protective procedures have not yet been established for the new polymeric materials, and the low resistance of some of these has led to costly failures of communication and electronic equipment. The few investigations that have been undertaken are with proprietary materials which often were of unknown or secret composition and could not be duplicated. As a result of these failures and lack of information, uncertainty and confusion exist in the specification of these materials for exposure in termite-hazardous areas.

BACKGROUND

One of the specific problems concerning the Navy in its shore-base operations has been with flexible PVC plastics used for cable sheathing and insulation. PVC polymers are excellent materials for cable purposes because of their good electrical properties, low cost, and high moisture and weather resistance, but, unfortunately, in flexible grades their resistance to subterranean termites is low. In 1965 the Navy Facilities Engineering Command (NFEC) requested NRL and the Department of Agriculture's Wood Products Insect Laboratory (WPIL), Gulfport, Mississippi, to jointly study methods for chemically increasing the resistance of flexible PVC formulations. NRL made up 32 PVC formulations of precisely known composition to test various methods of chemical inhibition of termites. These formulations consisted mainly of combinations of several added toxicants with various plasticizers. Specimens were exposed by NRL in Panama and by WPIL in Mississippi. Interim and final results of these data through 5 years of exposure have been reported (2-5).

None of the toxic materials were completely resistant under all conditions; however, a few showed a very high degree of resistance. The most effective formulations were those with a high concentration of the insecticides lindane and aldrin. Such potent

Table 1
Polymers Exposed to Subterranean Termites in Phase 2 Studies

Formulations: Category	Code	Mix*	Polymer Type	Alterations	Shore Hardness Scales: A	D	Composition	Remarks
Control and Comparison	A	1	Polyvinyl chloride (PVC)	None—Basic control mix	53	11	Basic[†] PVC A	A soft, nonadditive, nonresistant PVC for comparisons and evaluation of termite activity
	B	2	Polyvinyl chloride (PVC)	4%[‡] Added silica flour	68	15	Same as A plus 20 parts HiSil 303	Basic mix from previous study (Phase 1) included here as additional controls and to tie in Phase 1 and 2
Thickness and Smoothness Variations	A_1	14	Polyvinyl chloride (PVC)	Double thick	53	—	Same as A but made double thick	Thickness 100 mils instead of 50 mils
	A_2	27	Polyvinyl chloride (PVC)	Smoother surface	56	—	Same as A but with smooth molded surface	Compression molded surface instead of as milled surface
Hardness variations by Plasticizer Reductions	A_3	3	Polyvinyl chloride (PVC)	Hardness increased by reducing plasticizer 33%	—	22	Same as A except 67 parts DOP instead of 100	Some reduction in flexibility
	A_4	4	Polyvinyl chloride (PVC)	Hardness increased by reducing plasticizer 67%	—	48	Same as A except 33 parts DOP instead of 100	Considerable reduction in flexibility
	C	5	Polyvinyl chloride (PVC)	Hardness increased by reducing plasticizer 80%	—	60	Same as A except 20 parts dioctyl adipate (DOA) plasticizer instead of 100 DOP	Semirigid; could not be milled with DOP, but could with DOA
	A_5	21	Polyvinyl chloride (PVC)	All plasticizer omitted	—	80	Same as A except no plasticizer	Hard, rigid PVC
Internal Hardness Increased by Addition of Mineral Fillers	D	13	Polyvinyl chloride (PVC)	10% $CaMg(CO_3)_2$ (270-400)[§]	58	—	Same as A plus 53 parts dolomite sand	Soft angular crushed sand, Moh hardness = 3.5, 37-53 μ
	E	7	Polyvinyl chloride (PVC)	10% SiO_2 (270-400)	58	—	Same as A plus 54 parts silica sand	Hard smooth natural Ottawa sand, Moh hardness = 7.0, 37-53 μ
	E_1	9	Polyvinyl chloride (PVC)	10% SiO_2 (270-400)	62	—	Same as A plus 54 parts silica sand and 1% silane[¶]	Same as previous mix but with silane bonding agent
	E_2	10	Polyvinyl chloride (PVC)	5% SiO_2 (270-400)	59	—	Same as A plus 25 parts silica sand and 1% silane	Lesser amount of silica sand, 37-53 μ
	E_3	11	Polyvinyl chloride (PVC)	15% SiO_2 (270-400)	57	—	Same as A plus 83 parts silica sand and 2% silane -	Maximum workable addition of the silica and double silane
	E_4	8	Polyvinyl chloride (PVC)	10% SiO_2 (170-270)	62	—	Same as A plus 54 parts silica sand and 1% silane	Coarser particles of silica, 53-88 μ and silane
	F	12	Polyvinyl chloride (PVC)	10% SiC (270-400)	60	—	Same as A plus 60 parts fine carborundum	Very hard, sharp carborundum, Moh hardness = 9.1, size = 53-37 μ
	F_1	12F	Polyvinyl chloride (PVC)	10% SiC (<400)	60	—	Same as A plus 60 parts very fine carborundum	Very fine carborundum (SiC) < 37 μ
	F_2	25	Polyvinyl chloride (PVC)	15% SiC (<400)	60	—	Same as A plus 80 parts very fine carborundum and 2% silane	Maximum loading of very fine SiC with bonding agent
	F_3	26	Polyvinyl chloride (PVC)	15% SiC (<400) and harder with 33% less plasticizer	80	—	Same as A plus 80 parts very fine carborundum and 2% silane and 67 parts DOA instead of 100 DOP	Same as F_2 but harder and less flexible
	G	6	Polyvinyl chloride (PVC)	7% added fiberglass	70	—	Same as A plus 35 parts fiberglass	7% is a practical maximum for this mix, 1/4-in. fibers mill ground 10 minutes
	H	23	Polyvinyl chloride (PVC)	Creosote substituted for 50% of DOP plasticizer	65	—	Same as A except plasticizer is 50 DOP-50 whole creosote	Creosote-DOP is a satisfactory plasticizer but plastic slightly harder than A
Toxicants Added	I	16	Polyvinyl chloride (PVC)	Toxicant added	70	—	B formulation but 100 parts tricresyl phosphate (TCP) instead of DOP plus 2.6 parts aldrin	One of best formulations from first series. Contains high concentration of insecticide
	I_1	15	Polyvinyl chloride (PVC)	Toxicant added	73	—	Same as I but double thickness	Same formulation but double thick to provide a larger reservoir of insecticide
	I_2	18	Polyvinyl chloride (PVC)	Toxicant and 10% SiC (<400) added	72	—	Same as I but 10% SiC (<400) and 2% silane	Fine SiC and 2.6 parts aldrin to provide a combination of deterrents
Non-PVC Polymers	J	20	Ethylene propylene rubber (EPR)	None	56	—	Nordel 1070**	Selected for trial cable sheathing because of low cost, excellent weathering and electrical properties
	K	22	Chlorinated polyethylene (CPE)	None	55	—	Plaston[††]	Excellent electrical properties and weatherability and chlorination aids fungus resistance
	L	19	Chlorosulfonated polyethylene (CSPE)	None	50	—	Hyplon 40[‡‡]	Colorability with excellent weatherability, high ozone resistance, and fungus resistance
	M	24	Crosslinked polyethylene (XPE)	None	—	55	Petrothene XL 6301	Semirigid material with superior crack, temperature, and toughness properties over noncrosslinked PE

*Samples were marked with these numbers when fabricated.
†Basic PVC mix contains (parts by weight): 100 PVC resin (Geon 101), 100 plasticizer-dioctyl phthalate (DOP), 20 carbon black, 3.5 lead maleate, 2.0 dibutyltin laurate, and 30 whiting.
‡All percentages are by volume of total plastic, except silane.
§U.S. standard sieve sizes: 170 = 88 μ, 270 = 53 μ, 400 = 37 μ.
¶Silane coupling (bonding) agent Y2967 is added as 1% or 2% by weight of total filler.
**The ethylene propylene rubber contains (parts by weight): 100 Nordel 1070, 60 Philblack A, 10 stearic acid, 20 process oil, and 1.5 Thionex.
††The chlorinated polyethylene contains (parts by weight): 100 Plaston resin, 6.0 Epon 828, 10.0 Philblack A, 8 mercaptoimidazoline (NA-22), and 1.0 sulfur.
‡‡The chlorosulfonated polyethylene contains (parts by weight): 100 Hypion 40 resin, 30 Thermax, 10.0 Severn 100, 25 litharge, 0.5 2-benzothiazolyl disulfide (MBTS), and 2.0 Tetrone A.

chemicals have increasingly been recognized as very undesirable contaminants to natural environments, and their use in cable sheathing material may no longer be feasible. These insecticides have other disadvantages, too, in that they are hazardous materials in manufacturing and handling; furthermore, because of their high diffusion rates, they may lose their effectiveness over long periods of exposure. Australian scientists were also struggling with the problems of using flexible polymers in termite-active areas. Some of their investigations have indicated favorable results with silica sand as an additive to flexible PVC (6).

In recognition of these developments a meeting was called in 1967 by the NFEC with representatives of both the Navy and the Forestry Service. As a result of this conference it was decided to proceed with a second phase of the investigation, in which nonhazardous additives would be tested in flexible polyvinyl chloride plastics. Other suitable non-PVC formulations would also be investigated. The study was to be a joint effort of NRL and WPIL. As in Phase 1, the test materials were to be formulated by the Organic Chemistry Branch of NRL, so that compositions would be precisely known. Design of mixes, fabrication of samples, and exposure testing through 3 years have now been completed, and two interim summary reports have been submitted (7,8). The following will be a comprehensive final report combining the efforts of both organizations on this second phase, nontoxic portion of the study.

EXPERIMENTAL DETAILS

Materials Investigated

The basic plastics were PVC formulations with variations in hardness, thickness, plasticizer, and surface smoothness, and with the addition of a variety of fine particle mineral fillers. A few non-PVC formulations were included; they were selected on the basis of their suitability as cable sheathing material or for comparison with the PVC formulations. In all, 23 PVC polymers and 4 non-PVC polymers were investigated. A listing of all formulations is shown in Table 1.

Compounding Procedures

The various plastics were prepared by compounding the ingredients of each formulation on a roller mill operated at 260° F. The initial mix for each PVC formulation consisted of the resin, whiting, and plasticizer. After these constituents were blended, carbon black, lead maleate, and dibutyltin laurate were added, in the order given. Finally, the appropriate inert filler was added when used. A coupling agent (silane) was also added in some formulations to bind the particles of the inert filler to the plastic so that they could not be mechanically dislodged from the plastic matrix. After thorough mixing of the charge, the rollers were adjusted to give a 50-mil clearance and the plastic was sheeted off. When a toxicant was part of the formulation, it was added to the mix just prior to sheeting to allow only minimum exposure to heat. The total milling time for each charge was about 15 to 20 minutes; the milling time for the toxic additives was 5 minutes. The material, as it came from the mill, was sufficiently smooth and uniform to be used directly for preparing the specimens. All sheets were cut into 3-by-5-in. panels for later specimen fabrication. The non-PVC polymers were similarly compounded.

Exposure Conditions

Specimens were exposed to termites in four natural field environments and to accelerated attack experiments in the laboratory. In field exposures it is desirable to test in very active areas, so that controls and baitwood are generally attacked and a high probability of termite contact with each formulation is assured. Four sites were employed, two tropical and two Southern U.S., with different termite species at each. The following is a brief description of the locations:

1. U.S.D.A Forest Service test area (Cerro Cedro), Pacific side of the Panama Canal Zone, principal termite population: *Coptotermes*

2. NRL test bed (Navy Tank Farm) on the Caribbean side of the Panama Canal Zone, principal termite population: *Heterotermes*

3. Harrison Experimental Forest WPIL test area, termite population: *Reticulitermes*

4. Lake Charles, Louisiana WPIL exposure area, termite population: *Coptotermes formosanus*

Ten replicate 3-by-5-in. specimens of each polymer formulation were exposed at each location; specimens were normally 50 mils thick. Two exposure variations were used at both tropical sites; in one the plastic sheets were placed directly on the ground (flat) and covered with a 6-by-6-by-1-in. piece of untreated pine baitwood. Half of the samples were exposed in this manner. The other half were sandwiched between pieces of pine baitwood, with the bottom of the sandwich contacting the ground. These variations were placed in alternate rows, with all polymer formulations represented and randomly distributed in each row.

At Harrison Forest all ten samples of each specimen were exposed in the sandwich method. At Lake Charles, to take advantage of infested cypress stumps, specimens were separated by baitwood, bundled together, and buried in the ground. Bundles were installed radially around the stump. All formulations were represented and randomly distributed in each bundle. Figure 1 shows the various exposure sites and methods of exposure.

The laboratory trials were conducted by WPIL at Gulfport, Mississippi. In their jar test method a colony of approximately 4000 worker termites is placed in a quart mason jar with baitwood and soil, the mouth of the jar is covered with the test sample, and the jar is inverted. To escape from the jar the termites must perforate the test material. Both *Coptotermes* and *Reticulitermes* species were used for the jar tests. More details on the exposure methods are included in WPIL establishment and first progress report (7).

Specimen Evaluations

All of the field inspections were made jointly by an entomologist from WPIL, Gulfport, and a materials scientist from NRL, Washington. The specimens and the contacting baitwood were rated annually and by the same individuals throughout the course of the study. Ratings were by visual inspection according to the numerical scheme in Table 2.

a. Panama Canal Zone, Caribbean side, Navy Tank Farm

b. Mississippi, Harrison Experimental Forest

c. Panama Canal Zone, Pacific side, Cerro Cedro

d. Lake Charles, Louisiana, infested Cypress area

Fig. 1—Views of four field exposure sites

Table 2
Numerical Rating System

Numerical Rating	Polymer	Baitwood
0	No attack	No attack
1	Etching or very slight attack, $\lesssim$ 5 mils	Trace attack
2	Termites cutting into plastic to a depth $\approx$ 5-20 mils	Light attack
3	Termites cutting into plastic to a depth $\approx$ 20-35 mils	Moderate attack
4	Termites cutting into plastic to a depth $>$35 mils	Heavy attack
5	Perforation of sample	Very heavy attack

Table 3
Comparative Termite Activity in Field Exposure Beds

Summary of Damage to Two Nonresistant Control PVC Formulations (A and B) After 3 Years of Exposure

Exposure Location	Number of Control Samples Attacked (20 exposed)	Number of Control Samples Perforated (20 exposed)	Cumulative Damage Rating at 3 Years (100 possible)
Canal Zone, Caribbean side	20	17	93
Canal Zone, Pacific side	20	13	79
Lake Charles, Louisiana*	11	2	35
Harrison Forest, Mississippi	0	0	0

*The Lake Charles exposure was for 3-1/2 years.

RESULTS AND DISCUSSION

Comparison of Exposure Sites

Termite activity in the four natural exposure sites varied greatly. Table 3 shows the comparative results for the four beds after 3 years of exposure. From the data it can be seen that the termites in the two beds in Panama were much more aggressive than those in the U.S. beds. Between the two tropical sites there were only minor differences. At both tropical locations all the control PVC formulations were attacked, but penetration depths were slightly higher at the Caribbean; cumulative ratings after 3 years were 93 for the Caribbean vs 79 for the Pacific. The Caribbean side bed was newly established for this study. Termites there were practically all of the genus *Heterotermes*. The Pacific site was an older U.S.D.A. test bed in Fort Clayton, one that has always shown good activity. Both *Heterotermes* and *Coptotermes* are found there, with the latter predominating. The Lake Charles bed was established in an area known to be infested with

Coptotermes formosanus—the tropical subterranean termite that has recently been found in the continental U.S. (9).

It was anticipated that damage would be very rapid at Lake Charles, so much so that the first samples were read after only 6 months of exposure rather than the usual 1 year. As can be seen from the data, the degree of activity was disappointing; after 3-1/2 years only 11 of the 20 nonresistant control samples were attacked, and only two of 20 were penetrated. During the exposure period the Harrison Forest site was even worse. This was an old established test area that had a good record of termite activity, but during these 3 years no termites attacked either the samples or the contacting baitwood. Such a decrease or cessation of activity in specific areas is well known in biodeterioration studies—in fact, in an earlier study (5) a tropical bed at Galeta Island, Panama, lost most of its termite population after 10 years of reliable activity. The results of these studies clearly emphasize the necessity for conducting exposures in highly active areas and at more than one location.

Evaluation of Exposure Methods

In both tropical beds the two exposure methods described above (single baitwood cover and sandwich) were tried. There was very little difference between the two. All controls were attacked with both methods of exposure; 16 of the 20 were perforated in the sandwiches, while 14 of the 20 ground-contacting panels were perforated. Since the sandwich method keeps the specimens cleaner and easier to rate, it may be slightly preferable, although the need for more baitwood is a disadvantage. When dealing with toxicants, however, neither sample type was as desirable as the openly exposed dowel samples used in the first phase of this study (2); with the flat covered specimens the toxicant diffuses into the contacting wood or sheltered soil, where it sets up a preliminary barrier to termite attack, while the wood cover unnaturally protects the poison from rainwater or groundwater leaching.

Comparison of the 3-year natural exposures with the laboratory jar tests revealed the lab experiments to be a very effective method for accelerated screening of nontoxic materials. By the use of the two termite genera *Coptotermes* and *Reticulitermes* in the jar tests, different degrees of attack rate were obtained. The *Coptotermes*, being more aggresive, penetrated the materials much faster. Eventually, after 40 months of exposure, most of the materials perforated by the *Coptotermes* species were also perforated by the *Reticulitermes* species. With polymers containing insecticides the jar test was practically worthless because diffusion of insecticide into the jar was sufficient to destroy the captive termites.

Polyvinyl Chloride Polymers

Because of the current availability and the many advantages of PVC as insulating and cable sheathing material, these formulations were the principal polymers investigated. The most desirable procedure would be one that would make these materials resistant to termites by some physical change or nontoxic additive. In quest of this goal, trials were carried out by varying the thickness, surface smoothness, and hardness of PVC and sizes and classes of the mineral fillers.

Table 4
Termite Resistance of PVC Plastics

Effects of Changes in Thickness and Surface Smoothness

Formulations		Tropical Field Exposures for 3 years			Laboratory Jar Experiments (3 months) Number of Samples Perforated by Each Termite Genus	
Code	Type	Number of Samples Attacked (20 exposed)	Number of Samples Perforated (20 exposed)	Cumulative Damage Rating (100 possible)	*Coptotermes* (5 exposed)	*Reticulitermes* (5 exposed)
A	Basic control—50 mils thick, milled surface	20	18	96	5	5
A_1	Same formulation with milled surface but 100 mils thick	19	6	68	5	0*
A_2	Same formulation 50 mils thick but with smooth molded surface	16	6	59	†	†

*All five perforated after 7 months.
†Not tried in laboratory experiments.

Effects of Thickness and Surface Smoothness

The normal PVC specimen was 50 mils thick, with an as-milled surface. In the soft flexible condition this material is very susceptible to perforation by subterranean termites. It was considered that with a thicker specimen the termites might cut in and become discouraged before perforation, or that they might even be able to sense the thickness and not attack. Also it was postulated that if a very smooth surface was presented the termites would have difficulty initiating attack. Because of program limitations these parameters could not be investigated fully, but one double-thick (100 mils) set of specimens and one smooth-molded surface set were exposed at each of the two tropical locations and in the laboratory experiments. The effects of these two changes are shown by the exposure results presented in Table 4, wherein comparisons are made with the normal, 50-mil-thick, as-milled-surface control specimens.

The data reveal that with the thicker specimens the frequency of attack was practically unaltered, but only 1/3 as many perforations occurred. In the laboratory tests all double-thick samples exposed to *Coptotermes* were perforated within 1 to 2 months, but none were perforated in the first 3 months by the *Reticulitermes*, although all five control specimens were. These improved perforation results were expected. However, results with the smooth-surface materials were not as reasonable; it was thought the smoother surface might discourage initial attack, but not the depth once started. Although the perforations were again down by 2/3, the total attack was only slightly reduced.

Considering all the results, neither modification was sufficiently successful for practical dependence as termite deterrents. In conjunction with other adjustments, however, they may be useful in achieving reliable termite resistance of PVC formulations.

Effect of Hardness

From our previous test and those of others (6,10) it was known that PVC in the soft, flexible condition was nonresistant to subterranean termites, but at what degree of increased hardness (and reduced flexibility) resistance would be obtained was not definitely known. Possibly lower flexibility of a cable material could be tolerated if termite resistance could be achieved in this inexpensive, nontoxic manner. To investigate the hardness parameter, three mixes of the basic formulation with reduced percentages of plasticizer were tried, and a mix with no plasticizer was included. The results for these harder PVC mixes are shown in Table 5. The two controls with slightly different hardnesses are also included. The data indicate that increased hardness is a definite deterrent to termite attack.

In the accelerated laboratory tests sufficient hardness of the PVC formulations was a complete barrier to termite penetration. Although the A_3 mix, at 33% reduction in plasticizer and 22 D Shore hardness, was rapidly perforated by *Coptotermes*, the native *Reticulitermes* were unable to go through any of the five replicates during the full 40-months exposure. At 48 D hardness and above there was no penetration by any of the termite colonies in the laboratory.

For the jungle exposures, hardness of the PVC showed such a definite relation to termite resistance that it was possible to plot smooth curves for average penetration and number of perforations as functions of Shore D hardness (Fig. 2). The steep negative

Table 5
Effect of Hardness Variation on Termite Resistance of Polyvinyl Chloride Plastics

PVC Formulations			Shore Hardness Scale		Tropical Field Exposures for 3 years			Laboratory Jar Experiments (40-month results) Number of Samples Perforated by Each Termite Genus	
Code	Plasticizer				Number of Samples Attacked (20 exposed)	Number of Samples Perforated (20 exposed)	Cumulative Damage Rating (100 possible)	*Coptotermes* (5 exposed)	*Reticulitermes* (5 exposed)
	Content*	Type	A	D					
A	100	DOP	53	11	20	18	96	5	5
B	100†	DOP	68	15	20	12	76	5	5
A_3	67	DOP	—	22	19	4	64	5	0
A_4	33	DOP	—	48	4	1	7	0	0
C	20	DOA‡	—	60	2	0	2	0	0
A_5	0	—	—	80	0	0	0	0	0

*Parts plasticizer per 100 parts PVC resin.
†Basic DOP formulation from first phase of the study, contains 20 parts silica flour per 100 parts PVC resin.
‡Could not be milled with DOP, so DOA was used instead.

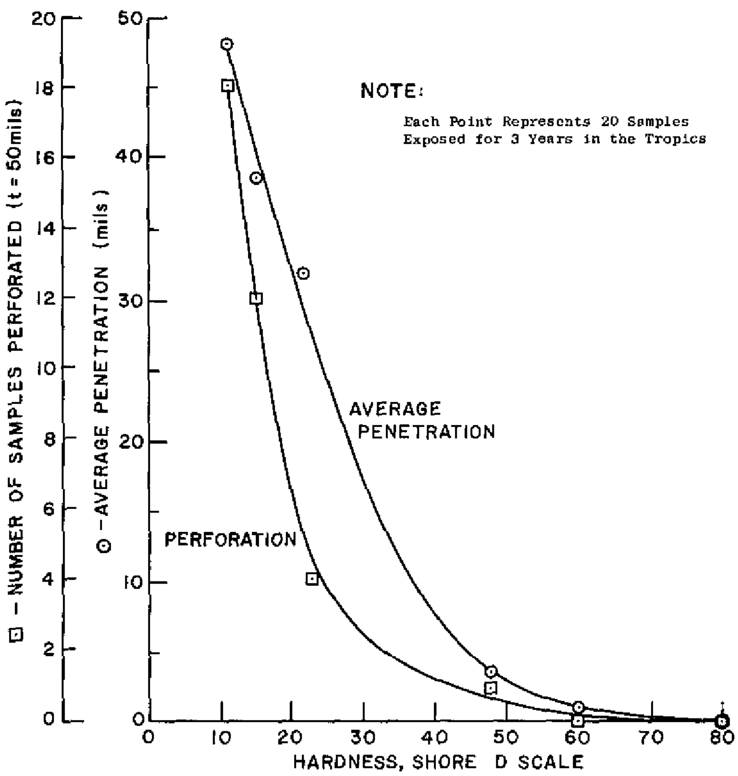

Fig. 2—Termite damage as a function of PVC hardness

slope of the curves between 15 and 35 D Shore shows that reduction in hardness in this range will considerably reduce the termite susceptibility of the plastic.

In view of these data for the harder and less flexible formulations, it would seem advisable, for termite-hazardous areas, to select as hard a PVC cable material as the installation and operation requirements permit.

Effect of Mineral Additives

One of the principal goals of the second-phase studies was to evaluate the effectiveness of mineral additives in flexible PVC plastics. The addition of reasonable amounts of finely divided inert filler to the polymer matrix does not adversely affect the flexibility of the the plastic, although penetration resistance as measured in the Shore hardness tests may be slightly increased. When the Australian scientists tested just 5% of fine silica sand as an additive, they found a considerable improvement in the termite resistance. They called the method "increasing the internal hardness" (5). In these present studies three different hardness inorganic granular materials were tried and three different size fractions of silica sand were investigated. When it was found that some of the mineral particles were easily dislodged from the plastic matrix, a silane coupling agent was used in some mixes to improve their adhesion to the plastic. Besides the granular materials, one formulation was made with the addition of fiberglass, cut into 1/4-in. lengths and mill-ground in the mix for 10 minutes. A summary of the exposure results for these mineral filler mixes, compared with the basic nonadditive control formulation, are presented in Table 6.

Table 6
Mineral Fillers as Termite Deterrents for Flexible Polyvinyl Chloride Plastics

Formulations		Tropical Field Exposures for 3 years			Laboratory Jar Experiments (3-month results) Number Samples Perforated by Each Termite Genus	
Code	Type	Number of Samples Attacked (20 exposed)	Number of Samples Perforated (20 exposed)	Cumulative Damage Rating (100 possible)	*Coptotermes* (5 exposed)	*Reticulitermes* (5 exposed)
A	Nonresistant neat control	20	18	96	5	5
D	10%* $CaMg(CO_3)_2$ (270-400)†	18	9	62	5	3
E	10% SiO_2 (270-400)	20	12	76	5	5
F	10% SiC (270-400)	14	6	47	5	1
E_2	5% SiO_2 (270-400)‡	20	5	68	5	0
E_1	10% SiO_2 (270-400)‡	20	5	57	5	2
E_3	15% SiO_2 (270-400)‡	20	5	55	5	0
E_4	10% SiO_2 (170-270)‡	19	6	64	5	2
E_1	10% SiO_2 (270-400)‡	20	5	57	5	2
F_1	10% SiC (<400)	20	8	61	5	0
F_2	15% SiC (<400)‡	13	7	50	5	¶
F_3	15% SiC (<400)‡ §	6	0	13	¶	¶
G	7% Fiberglass	16	4	42	5	2

*All percentages of fillers are by volume of total mix.
†U.S. standard sieve sizes (170 = 88 microns, 270 = 53 microns, 400 = 37 microns).
‡Contains silane bonding agent (Y 2967).
§Also increased hardness by 1/3 reduction of plasticizer (Shore 80A).
¶Not tried in this experiment.

Examination of these results shows that, generally, the number of samples attacked was only slightly decreased with most of the mineral fillers, but on the whole the number of perforations was appreciably reduced. However, only one formulation, F_3 (containing one-third less plasticizer), showed no perforations. Resistance was probably more the result of increased hardness than effectiveness of the filler.

The grouping of formulations in Table 6 is arranged so that certain comparisons can be easily made. The first group of three compares filler materials of widely varying hardness. Dolomite sand $CaMg(CO_3)_2$ with a Moh hardness of 3.5, silica sand (SiO_2) with a Moh hardness of 7.0, and fine carborundum (SiC) with a Moh hardness of 9.1 were all tried at 10% of the total mix volume. It was anticipated that the very hard, sharp SiC might be a superior deterrent due to its probable cutting and abrading of termite mandibles. From the exposure results it can be seen that some reduction in attack was obtained with the SiC additive, but the beneficial effect was not as great as hoped for; 14 of the 20 samples were attacked to some degree and 6 were perforated. The slight superiority of dolomite over the harder silica sand may have been the result of better bonding to the matrix provided by the more angular shape and rougher surfaces of the limestone particles. These three mixes did not contain the silane coupling agent.

The next group of three formulations in Table 6 shows the effects of different quantities of filler. They differ from the previous three in having a silane bonding agent incorporated in the plastic mix. Very little difference is evident between the 5%, 10%, and 15% silica additions. A slight trend is shown in the cumulative penetration ratings with 68, 57, and 55 respectively for the 5%, 10%, and 15% additions. Fifteen percent was about the maximum amount of material that could be added without adversely affecting workability and flexibility.

In Table 6, formulations E from group 1 and E_1, from group 3 were identical, except that a silane bonding agent was used in E_1. Comparison of these two mixes provides an evaluation of the effectiveness of the silane additive. There seems to be moderate improvement with silane, as the total perforations were reduced from 12 to 5 in the field and 10 to 7 in the laboratory.

The third group of four formulations provides comparisons of various size fractions of mineral fillers, ranging from 88 μ to a very fine material of <37 μ. Again the differences in termite damage were not conclusive, ranging from 5 to 8 specimens perforated out of 20 exposed. The lowest number of perforations was obtained with the 53-37 μ size fraction (270-400 mesh). The slight advantage for this size over the finer-particle filler is also borne out in the comparison of the F and F_1 SiC mixes.

The addition of 7% fiberglass (a practical maximum) in formulation G provided above average effectiveness in the field exposures, with only 4 perforations out of 20. However, in laboratory tests only average results were obtained for fiberglass, with 7 perforations out of 10 exposures in 3 months. Also the PVC with fiberglass was slightly harder, 70 A vs 53 A for controls, which may have increased resistance.

To be rated highly resistant to subterranean termites for all natural exposures, a material should have completely resisted perforation during the 3 years of tropical bed testing and also exhibited much improvement over the neat PVC in the lab jar tests. None of the filler-additive formulations met either of these criteria. Mineral fillers can probably assist in improving termite resistance of PVC formulations when used in conjunction with other alterations, such as increased hardness or surface smoothness. In this manner the desired degree of resistance may be obtained without resorting to toxic additives. However, before relying completely on these combinations of physical deterrents, they should be screened by a series of laboratory jar exposures, and the best combination obtained should then be tried in the tropical bed exposures.

Other Polymers

It was hoped in this study that some of the alterations in the PVC formulations would offer a high degree of resistance, especially in view of the favorable report for a mineral filler by the Australian investigators. However, the possibility remained that none of the PVC formulations might be effective. This idea was reinforced when gouging the materials with a fine needle point under a microscope showed the PVC to be almost putty-like and easy to gouge, while polyethylene and synthetic rubbers had tougher, more resilient surfaces that were difficult to damage. It was therefore decided to select a few other non-PVC polymers for inclusion in this study.

Selection was necessarily limited in number, and only a few materials which were considered to have the most potential as useful substitutes for PVC in electronic cable applications were chosen. In one case a semirigid material M was included for comparison with hard PVC. As with the PVC formulations, all the other polymers were compounded and fabricated into specimen panels at NRL and tested concurrently with the PVC formulations in the laboratory and field exposures. The materials included were:

1. Ethylene propylene rubber (EPR)—a relatively new material of low cost with excellent weathering and electrical properties.

2. Chlorosulfonated polyethylene (CSPE)—a polymer offering good electrical properties and excellent weather resistance which, unlike most other elastomers, can be permanently colored without losing its high degree of weatherability. Its resistance to ozone is unexcelled, which is an important consideration for tropical applications.

3. Chlorinated polyethylene (CPE)—a higher-density polyethylene with excellent weathering and electrical properties; the chlorination increases its density and also improves its resistance to fungus.

4. Crosslinked polyethylene (XPE)—a semirigid material with superior crack, temperature, and toughness properties over noncrosslinked polyethylene. Table 7 is a summary of the field and laboratory results with these four polymers. One of the best filler-modified PVC formulations, F, and a hard PVC formulation, A_5, have been included for comparison.

All of the flexible non-PVC formulations tested were superior to the best of the flexible PVC formulations. This was also found to be true in another investigation in which specimens were exposed in the marine environment (9). There were no perforations on any in the field exposures, while the modified PVC formulations ranged from 5 to 13 perforations for 30 samples exposed per formulation. Of the 20 soft flexible materials in the study, ethylene propylene rubber (H) and chlorosulfonated polyethylene (J) were the two most resistant. Between the two there was no clear-cut advantage for either. The EPR (J formulation) was almost immune to attack in the natural exposures, receiving only one exploratory nibble on the 30 samples exposed to tropical termites (20 in Panama and 10 in Louisiana), but in the captive-colony capped-jar experiments in the laboratory at Gulfport all 5 of the specimens were perforated by the *Coptotermes*

Table 7
Comparative Resistance of Non-PVC Polymers

Formulations		Shore Hardness (Scale A or D)	Tropical Field Exposure for 3 years			Laboratory Jar Experiments (40-month results) Number Samples Perforated	
Type	Code		Number of Samples Attacked (20 exposed)	Deepest Penetration*	Cumulative Damage Rating (100 possible)	*Coptotermes* (5 exposed)	*Reticulitermes* (5 exposed)
Ethylene propylene rubber	J	56A	1	1	1	5	2
Chlorinated polyethylene	K	65 A	11	3	18	4	3
Chlorosulfonated polyethylene	L	55 A	4	2	6	0	0
One of best flexible PVC formulations with filler†	F	60 A	14	5	47	5	5
Crosslinked, hard polyethylene	M	55 D	2	1	2	0	‡
Hard PVC (80% reduction in plasticizer)	C	60 D	2	2	4	0	0

*Rating: $1 \lesssim 5$ mils, $2 \approx 5$-20 mils, $3 \approx 20$-35 mils, $4 \approx 35$-50 mils, 5 = perforation, (50 mils)
†Filler was 10 vol-% of 270-400 mesh SiC.
‡Not exposed to *Reticulitermes.*

species of termite within 3 months, and 2 of the 5 exposed to *Reticulitermes* were perforated by the end of 40 months, showing that under extreme conditions the material can be penetrated by termites. The chlorosulfonated polyethylene was not quite as good in the field exposures with 6 samples out of the 30 being nibbled by termites and 21 to a depth of 5 to 20 mils; but these damages are slight and the CSPE material can be considered highly resistant. In the laboratory experiments with CSPE not a single sample of the 10 exposed to the two termite species was perforated during the 40-month test period; this was the only flexible polymer in the investigation that did not sustain a single perforation during the full period of laboratory jar testing.

These two polymers appear worthy of serious consideration for termite-hazardous areas. Engineering and economic feasibility studies should be made for specific applications; with their nontoxicity and promise of low maintenance and failsafe operation, one or the other of these two polymers should be a most logical materials choice.

The crosslinked polyethylene was included for comparison with the harder PVC formulations. As already shown, increased hardness proved to be so effective in repulsing termites that both the A_5 formula PVC and the M formula XPE at Shore hardnesses of 55 D and 60 D respectively were almost completely resistant in all exposures. If this degree of hardness can be tolerated, either the M or A_5 formula can be used with little or no risk of termite damage.

Toxic vs Nontoxic Deterrents

Of the three serious objections to toxic additives—environmental contamination, manufacturing and handling hazards, and eventual loss of effectiveness—the first seems to be the most troublesome and insurmountable. Recognition by the Navy and the Department of Agriculture of the possibility of environmental damage was an important stimulus in implementing the second phase of these studies.

Two formulations, B and I, were included in both studies. The B formulation was a nontoxic control and provides a comparison of attack intensity for the two different exposure conditions. The phase one tests were with the dowel-type specimens exposed at Galeta Island, Panama. Fourteen of the 15 samples exposed were attacked but only one of these was perforated, while with the same B formulation in the second phase, with the flat bait-contacting samples, 20 of the 20 were attacked and 12 were perforated. This large difference was due to increased bed activity, the greater vulnerability of the exposed samples, or both. While it is not possible to assign the exact ratio of importance of these two factors, it is obvious that the nontoxic samples in the second phase were exposed to greater termite pressure.

The toxic formulation I (2.6% aldrin) included in the second series should have contributed to the toxic vs nontoxic comparison, but it did not because of the shielding effect of the baitwood, which prevented normal leaching of the toxicant. Not only were the I samples completely untouched, but the contacting baitwood was attacked much less than baitwood contacting nontoxic samples. This was due to transfer of insecticide into baitwood and the soil below. The laboratory tests also failed to provide comparative data because diffusion from the toxic samples quickly killed the captive termite colony.

The only reasonable comparison then is that of the best formulation from each phase, recognizing, of course, that the nontoxics were exposed under relatively more severe conditions. Of the 15 specimens containing 2.6% aldrin with TCP plasticizer exposed at Galeta Island, Panama, there was no termite attack on any during 3 years of exposure. For the same time span 20 samples of ethylene propylene rubber exposed at Gatun and Clayton, Panama, received only one superficial nibble to a depth of about 5 mils. These two formulations can both be considered highly resistant and selection should be based on other considerations, such as economics, toxic hazards, or life expectancy requirement.

One other toxicant was tried in this portion of the study. This was H, in which whole creosote was substituted for one-half of the DOP plasticizer. The combination worked satisfactorily as a plasticizer but provided only mild improvement in termite repellency. It was the only toxic formulation tested that did not kill the laboratory captive colonies in jars. Both species of termites used in the jars were able to survive and penetrate the creosote-bearing plastic. The *Coptotermes* colonies perforated all 5 specimens within 3 months. The native *Reticulitermes* were unable to perforate any in 3 months, but 3 of 5 were perforated after 40 months. In the field exposures the results were inconclusive because of creosote absorption into contacting soil and baitwood; even so, 5 of 30 samples were attacked with the maximum depth of penetration being greater than 35 mils.

SUMMARY AND CONCLUSIONS

1. The 27 polymer formulations, exposed to different termite species in four natural sites for periods of 3 to 3-1/2 years, exhibited quite varied resistance to subterranean termites, ranging from 1 to 36 specimens attacked of the 40 exposed for each formulation.

2. Extreme differences in activity were found for the different exposure sites, ranging from intense in the Panama tropics to none in one of the southern U.S. areas.

3. Comparison of exposure methods showed only slight differences between the ground-contacting polymer/baitwood cover array and the baitwood/polymer/baitwood sandwich-type specimen. Both seemed to provide maximum vulnerability of the specimens to termites. However, for toxic materials the uncovered dowel type specimens are preferable.

4. The captive-colony laboratory jar experiments were very effective for obtaining accelerated test data on the nontoxic polymers. Agreement with the outcome of the 3-year natural exposures was generally good. In these tests the *Coptotermes formosanus* penetrated the polymers much more rapidly than the *Reticulitermes* species.

5. Modest improvement in termite resistance of PVC plastics was obtained by doubling the thickness of the samples from 50 to 100 mils. With this physical alteration total perforations were reduced from 19 to 5 in the natural exposures.

6. Changing from an as-milled surface to a smooth, molded surface also improved the perforation resistance of the PVC. Total samples perforated were reduced from 19 to 6. Unexpectedly, only a slight reduction (20 to 18) in the total number of specimens attacked was obtained with the smoother surface.

7. For PVC, the hardness parameter was clearly the most significant. Small increases in hardness in the 10 to 35 Shore D range considerably increased termite resistance,

and above 48 Shore D there were no perforations in either the laboratory or natural exposures.

8. Of the several types of mineral fillers tried in various size ranges, hardnesses, and additive percentages, none were completely effective, although most of them significantly reduced termite penetration in the natural bed exposures. The two best seemed to be fiberglass and 10% SiC (270-400 mesh).

9. The highest resistance found for the soft, flexible materials was with the non-PVC formulations. EPR and CSPE were both immune to perforation in the natural exposures, and the latter was the only flexible formulation not perforated in the 40-month laboratory experiments.

10. The requirements for different exposure conditions did not permit direct comparison of the nontoxic polymers with insecticide-bearing PVC formulations. However, the best of the nontoxic formulations tried were about equal to the highest concentrations of lindane and aldrin tested, and without the environmental and handling hazards associated with these strong insecticides.

ACKNOWLEDGMENTS

This study would not have been possible without the interest and assistance of a number of individuals. The authors particularly extend thanks to Dr. John M. Leonard of NRL who has been closely associated with this work since its inception and who has contributed many valuable suggestions. Mr. Ralph Taylor, Polymer Consultant for the Chemistry Division at NRL, who provided much of the expertise for formulating the basic PVC and non-PVC formulations. Mr. Harry Nash of the Polymer section at NRL who supervised the milling and fabrication of the polymer specimens, and Mr. Roddy Daniels and Mr. Kenneth Tynes of WPIL, Gulfport, who ably assisted in most of the field and laboratory exposures and inspections. In the Panama Canal Zone, Mr. William Gaylord of the Army Corps of Engineers, Mr. Charles W. Hummer, Pollution Control Officer of the Panama Canal Co, and Mr. Elton Bell of the Fuels Division, Rodman Naval Station, were all extremely helpful in establishing and inspecting the tropical exposure beds.

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